

CALL RECORDINGS

We recorded frog calls over two time periods: September 2005 - December 2005 and September 2006 - January 2007. We only recorded when weather conditions were dry and still, with wind speeds ≤ 3 m/s. Before and after recording, we measured wet and dry bulb temperature using a Zeal (Merton, UK) whirling hygrometer, and wind speed using a Kestrel 3000 (Mt Eliza, Australia) pocket weather meter. We took a water temperature reading near the calling frogs using a Fluke 52 II (Everett, USA) thermocouple thermometer with a Fluke 80PK-1 bead probe.

MEASUREMENTS OF BODY SIZE IN *LITORIA EWINGII*

Male frogs were located by call and captured by hand using inverted plastic freezer bags, before being transferred to plastic snap-lock bags to be measured with vernal calipers. We used a new bag for each frog, to avoid the transfer of pathogens between individuals. To exclude inter-observer error, a single researcher took all measurements. She took three separate measurements of snout-vent length for each frog, which were then averaged to give the value used in our analysis. After measuring, each frog was released near the point of capture. As *L. ewingii* often calls from dense vegetation, locating and capturing the frogs was very time-consuming. Given time constraints, we were able to catch and measure 63 individuals across 12 sites.

ESTIMATION OF TRAFFIC NOISE

We collected data on daily traffic volume, traffic speed, and percentage of commercial vehicles from local councils and the state road authority, VicRoads for use in the Calculation of Road Traffic Noise (CoRTN) model (Department of Transport 1988). We calculated the noise contributed by all relevant roads near a site, corrected for traffic speed, proportion of commercial vehicles and distance, and then combined these values to give a single noise level for each site. We assumed that the gradient of all roads was 0%, that traffic speeds were constant, and that the source and reception points were at the same height. Only roads with a traffic volume ≥ 50 vehicles/hr were included in the analysis (Department of Transport 1988). We did not have data on the traffic volume of three roads near survey sites with *L. ewingii* and two roads near survey sites with *C. signifera*. Therefore, we estimated the traffic volume on these roads using a probability distribution of known traffic volumes on different classes of roads. The CoRTN estimate of traffic noise was strongly correlated with the average noise level measured with the sound-level meter at sites without continuously chorusing frogs (e.g., $r = 0.79$ for *L. ewingii*, $n = 13$), indicating that it was a reasonable surrogate for traffic noise at the time of recording.

ANALYSIS OF CALLS

Every *L. ewingii* call that did not overlap substantially with another call was included in the analysis. When there was a continuous chorus, the recording was divided into 2.6-second segments, and each segment treated as an individual call. Individual calls were

used as the unit of analysis, nested within sites. As it was not possible to analyse every *C. signifera* call recorded, we used the following criteria to include calls for analysis. All calls that did not overlap substantially with other calls were included. Where there was a continuous chorus, we analysed all distinguishable individual calls in a one-second segment every ten seconds of recording. If individual calls could not be distinguished, a lower and upper frequency value was recorded for the one-second segment. When there was only one individual frog calling in a one-second segment, we examined the whole ten-second segment to isolate each call. Individual frogs could be recognised aurally and by call intensity, call length, and call pattern. An average value of lower and upper frequency was calculated for each frog at each site, and used as the unit of analysis, nested within sites.

STATISTICAL MODELING

*Body size of *Litoria ewingii* as a function of traffic noise*

We used hierarchical, Bayesian linear regression in OpenBUGS (Spiegelhalter et al. 2006, McCarthy 2007) to model the effect of traffic noise on body size in *L. ewingii*. The model accounted for dependence between the sizes of frogs at a survey site, effectively treating each individual as a random sample of all individuals calling at a site. Using uninformative priors gives results that are numerically similar to those based on maximum likelihood estimation. We estimated posterior density functions from 100,000 iterations of OpenBUGS after discarding the initial 10,000 iterations as a burn-in. We centred the explanatory variable (traffic noise) by subtracting the mean from each value, to help reduce auto-correlation between successive samples from the Monte Carlo Markov Chain (MCMC) algorithm.

Effects of traffic noise and temperature on call frequency

We also used hierarchical, Bayesian multiple linear regression in OpenBUGS to model the effects of traffic noise and ambient temperature on call frequency. Both models included a random site effect to account for variation in call frequency that was not explained by traffic noise or temperature. Based on an analysis of skewness and kurtosis (McCarthy 2007), the data were approximately normally distributed. The regression models accounted for dependence between the calls recorded at a survey site, treating each call as a random sample of all possible calls at a site. Although we centred the explanatory variables, there was still high auto-correlation between successive samples from the MCMC algorithm and the models took a long time to reach the stationary distribution. We therefore discarded the first 100,000 samples as a burn-in, before taking 100,000 samples (every tenth sample of one million samples) from the posterior distribution to estimate parameters.

Comparison of the frequency shift with noise in birds and frogs

We compared the frequency shift in urban noise observed in three species of birds (Slabbekoorn and Peet 2003, Fernández-Juricic et al. 2005, Wood and Yezerinac 2006)

with the frequency shift in traffic noise we observed in *L. ewingii* and *C. signifera*. For all species, we used the predicted signal frequency at 47 dB of noise as the denominator in our calculations of % change in frequency. We converted the noise measurements of Fernández-Juricic et al. (2005) from RMS amplitude in μPa to dB SPL to enable comparison with the other studies. While the studies on birds did not distinguish traffic noise from general urban noise, it is likely that traffic noise was a large component of the noise recorded (Slabbekoorn and Peet 2003, Fernández-Juricic et al. 2005, Wood and Yezerinac 2006).

MATHEMATICAL MODELING OF ACTIVE DISTANCE IN *LITORIA EWINGII*

We recorded traffic noise 7.5 m from the edge of the Eastern Freeway in Melbourne at 2030 hrs using a Marantz PMD670 digital recorder and a single Røde NT5 cardioid condenser microphone. The recording had a sampling frequency of 48 kHz. We calculated the average frequency distribution of the traffic noise in Adobe Audition 2.0 from eight 30-second segments of recording, using a Blackman-Harris window and an FFT length of 1024. Available data indicate that the auditory thresholds of *L. ewingii* are constant across the range of call frequencies observed in this study (Loftus-Hills and Johnstone 1969, Loftus-Hills 1973), so there should be no important change in the sensitivity of female receivers with increasing call frequency. Therefore, the active distance of the call of *L. ewingii* in traffic noise should be mainly a function of reduced masking at higher call frequencies.

We used the following parameters in the mathematical model: a male frog calling from an elevated position (50 cm above the ground) at an amplitude of 91 dB root mean squared (RMS) SPL at 50 cm, with the hearing thresholds of the female receiver set at 63.8 and 62.4 dB SPL. We used a root mean squared value for call amplitude because as an average value, it is appropriate for estimating the efficiency (and therefore the energetic cost) of sound production (Prestwich et al. 1989). The peak amplitude of the advertisement call of *L. ewingii* recorded by Loftus-Hills and Littlejohn (1971; 101 dB) can be considered to represent the maximum RMS SPL, which is approximately 3 dB lower than the true peak amplitude of a signal (Gerhardt 1975). In the genus *Hyla*, the RMS SPL of a frog call at 50 cm is 11 dB lower on average than the true peak amplitude (Gerhardt 1975). Using this information, we estimated the highest amplitude of the advertisement call of *L. ewingii* in RMS SPL at 93 dB ($= 101 + 3 - 11$). We used a value of 91 dB RMS SPL in our model of the active distance of the *L. ewingii* call in traffic noise, as this was close to the highest amplitude known for the species.

Ehret and Capranica (1980) demonstrated that masking susceptibility (the difference between the tone level at the masked threshold and the spectrum level of noise needed for complete masking) in *H. cinerea* was approximately 25 dB at 2.5 kHz. This means that the spectrum level of a 2.5-kHz tone needed to be 25 dB higher than the spectrum level of the background noise at the same frequency to be detected by the frog. We calculated the higher and lower female hearing thresholds by adding 25 dB to the average spectrum level of traffic noise in a 140-Hz band around the dominant frequency of the *L. ewingii* call predicted at the quietest and noisiest sites, respectively, when the overall traffic noise

level was 77 dB. Ehret and Gerhardt (1980) estimated the width of the critical-ratio band (the part of the frequency spectrum that contributed to masking of a signal) to be 140 Hz at 3 kHz in *Hyla cinerea*. The difference between the active distances of the call at the two hearing thresholds gave the change in active distance with the observed frequency shift in traffic noise.

LITERATURE CITED

Ehret, G., and H. C. Gerhardt. 1980. Auditory masking and effects of noise on responses of the green treefrog (*Hyla cinerea*) to synthetic mating calls. *Journal of Comparative Physiology* **141**:13-18.

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